Study of Bicycle Parking in Central Business District of Shanghai

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Bicycles are a frequently used transportation mode in the cities of China. Unavoidably, bicycle parking is becoming a serious problem in urban areas, especially in the central business district (CBD). A bicycle parking study in the CBD of Shanghai, begun in 1987, includes data collecting, parking generation modeling, and parking demand forecasting in the predicting year and suggests a parking plan for the year 2000 and a management package to improve short-term bicycle parking in the CBD.

In Shanghai, there are 7 million registered bicycles, almost 0.7 bicycle for each person. Bicycles influence peoples' everyday lives. Most people ride bicycles not for recreation or exercise but for work, shopping, school, and other trip purposes. Studies of mode selection in the city of Shanghai indicated that 40 percent of commuters are bicycle riders (*1*). Because of the level of economy development and the construction of a transportation facility, bicycles as a travel tool play and will continue to play an important role in urban transportation. Experts have forecasted that bicycles as a major transportation tool will survive into the next century.

The bicycle is a clear transportation mode. No air pollution is caused by bicycle traffic. To the residents of Shanghai, riding a bicycle is a convenient mode of short-distance transportation to access the city's downtown area, especially when the traffic congestion occurs in the area. This is why so much bicycle traffic is attracted to the central business district (CBD) of Shanghai. Compared with public transit, however, bicycle traffic occupies many road and land resources, both in moving and parking. In the CBD of Shanghai, traffic is extremely dense because the roads are insufficient. In addition, parking bicycles on the street causes even worse traffic conditions.

Bicycle parking is a puzzling problem to CBD transportation management officials. Continuous studies focusing on bicycle parking in the CBD have been carried out since 1987. Research topics such as *Parking Survey and Study in Shanghai* and *Studies on Parking Management and Strategy in CBD* have been done by a research team of the Shanghai Institute of Urban Construction (*2*). The achievement of such studies is the foundation of this paper.

In this paper, the demand and supply of bicycle parking and the distribution and behavior of parking time and space are discussed. Two types of bicycle parking models have been calibrated and tested. The input parameters used in those models are the numbers of employment positions and bicycle trip (destination) attractions. Short- and long-term schemes and strategies to improve the bicycle parking in Shanghai's CBD have been suggested. The results of the studies have been applied to the comprehensive urban transportation planning and transportation system management by the Shanghai municipal authority (*1,3*).

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CHARACTERISTICS OF BICYCLE PARKING IN SHANGHAI'S CBD

The CBD of Shanghai is the economic, commercial, and financial center of the city and is the largest trip attraction in the city. A high demand for bicycle parking as well as vehicle parking is an important aspect of transportation in the CBD.

Quantitative analysis of bicycle parking characteristics, which is based on the continuous on-site survey and data collection in the CBD of Shanghai, helps elucidate the bicycle parking situation in the CBD. Bicycle parking characteristics can be described by such parameters as the total amount of parking demand and supply, parking duration, maximum parking accumulation, and the behavioral characteristics of the parking demand.

Parking Demand and Supply

The distribution of space and time in parking accumulation in the city central area (CCA, covering 29 zones and about 8 km^2) and in the CBD (14 zones coded from 101 to 114 and about 4.16 km^2) are shown in Figure 1 and Figure 2. The maximum parking accumulation of the CCA and CBD, which both appear at 10:00 a.m. and 4:00 p.m. are 35,000 and 24,700 vehicles, respectively.

Most bicycles in the CCA park on the street. There are 14,529 and 9,601 legal parking spaces for bicycles in the CCA and CBD, respectively. Maximum parking saturations (the ratio of maximum parking accumulation and parking space) for CCA and CBD are 2.76 and 2.57. This indicates that bicycle parking in both the CCA and CBD is greatly oversaturated (see Figure 3).

Parking Duration

Parking duration is closely related to trip purpose and land use. Statistical data indicate that the average duration of on-street parking is 30 min and the duration in a recreation area (from 50 to 80 min) is longer than the average. The longest duration, of course, is found in parking for work or for transfer of the travel mode from bicycle to transit in the trip for work. Figure 4 gives the parking time distribution for various trip purposes.

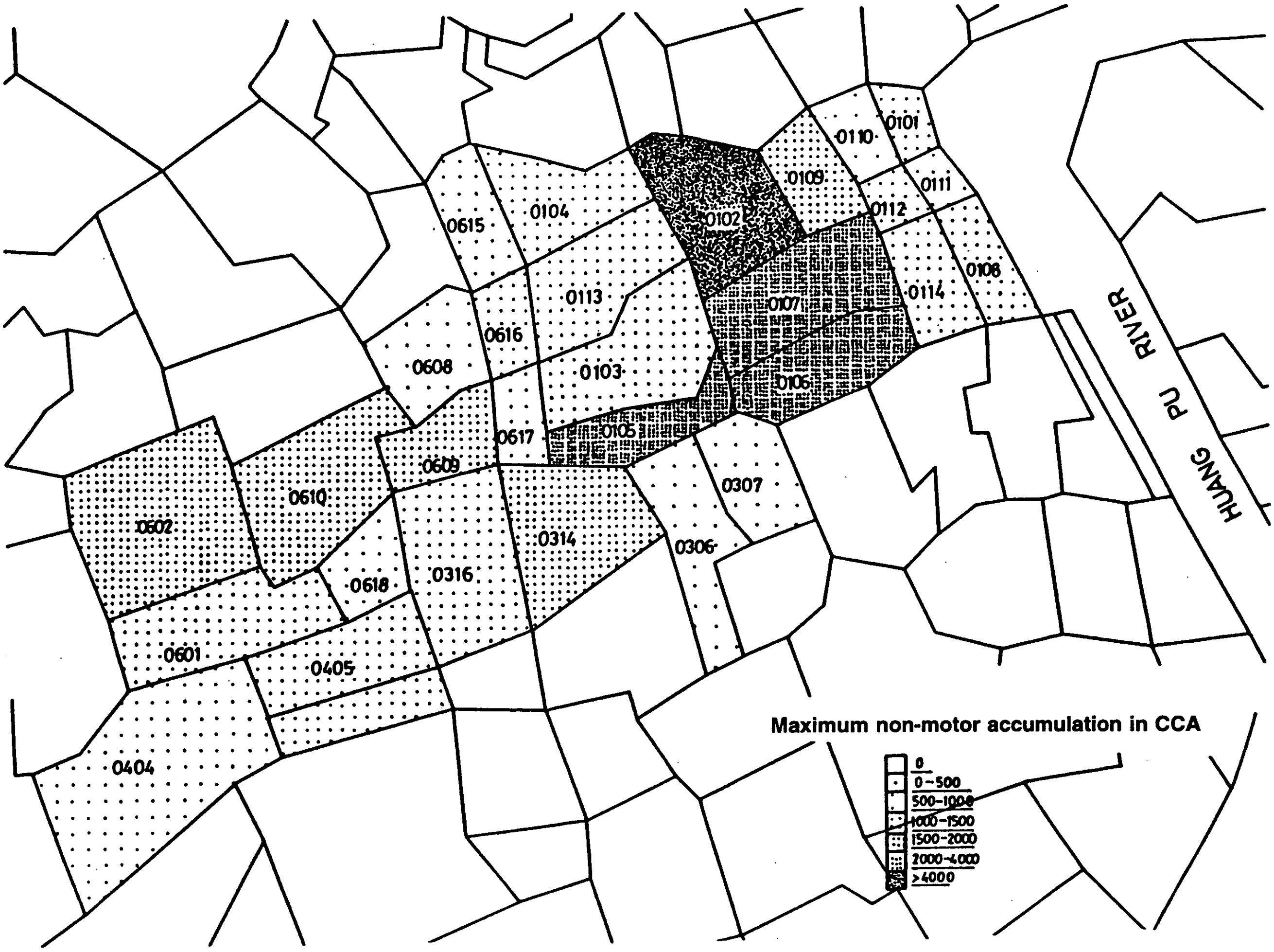

FIGURE 1 Distribution of bicycle parking spaces in Shanghai CCA and CBD.

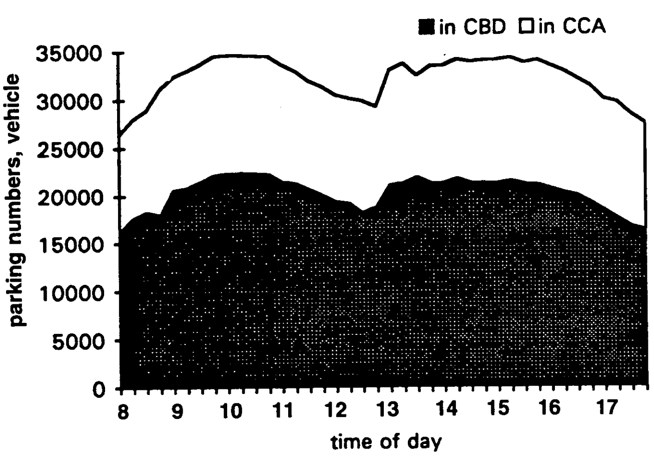

FIGURE 2 Bicycle parking accumulation in Shanghai.

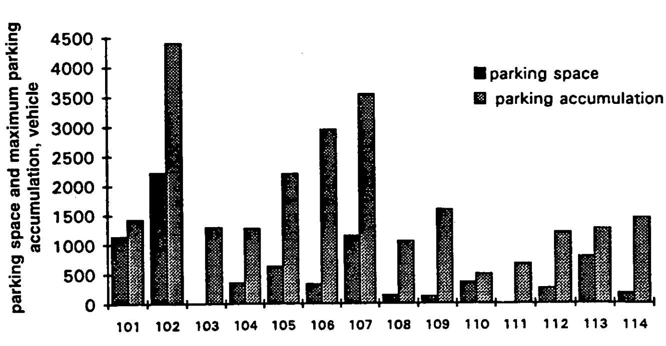

FIGURE 3 Bicycle parking supply and demand in Shanghai CBD.

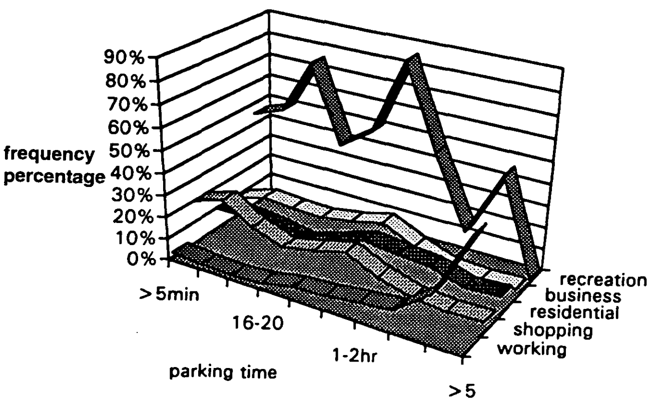

FIGURE 4 Distribution of parking time by trip purpose.

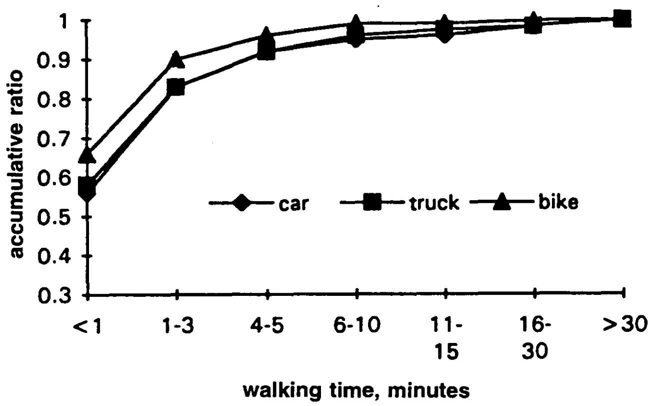

FIGURE 6 Distribution of parkers' walking time.

Parking Purpose Distribution

In the CBD, most bicycle riders are parking for shopping (about 40 percent), whereas those parking for business and work are 8.4 and 10.2 percent, respectively (see Figure 5).

Walking Time Distribution

The walking distance for bicycle riders after parking is shorter than that for motor vehicle drivers (see the accumulation curve in Figure 6). About 67 percent of riders walk a distance that is within 1 min of parking. This indicates that most bicycle riders do not want to walk long distances after parking.

Influence Factors of Parking Decision Making

A total of 4 influence factors (i.e., walking distance, safety, toll fee, and convenience in finding a parking place) and 790 samples of bicycle riders were selected for the study in June 1993. The first consideration for more than 80 percent of riders is walking distance (see Table 1). The weighted average of the order of riders' consideration is distance, security, toll-fee, and convenience, in turn. The tolerance level for walking distance after parking is 300 m (74 percent of interviewees, see Table 2).

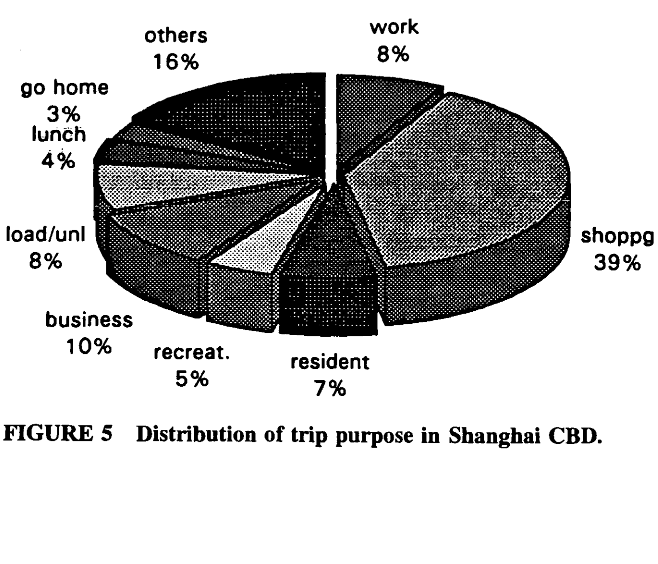

FIGURE 5 Distribution of trip purpose in Shanghai CBD.

Comments on Parking Payment and Travel Mode Selection

Payment for parking is not widely tolerated by most riders. The acceptable parking fee is 0.20 yuan (91.24 percent of the sample). Because most bicycle drivers believe that parking should be free because of the lower level of service in public transit, 78.01 percent believe that they will change the travel mode from bicycle to transit only if the travel time of transit becomes shorter than that on a bicycle. A total of 63.6 percent of bicycle riders expect to have a motorcycle even if the price of it is twice their monthly income.

FORECASTING DEMAND IN CBD BICYCLE PARKING

Forecasting the demand for bicycle parking precisely in a particular year is the foundation of bicycle parking planning in the CBD, the most concentrated source of traffic in the city. Two types of a parking demand forecasting model were set up by the authors: one is the model of the relationship between parking demand and land use, a kind of category analysis model, in which the intensity of land use in the city can be expressed by the number of employment positions; the other is the relationship between parking demand and trip attraction—a linear regression model.

Relationship Between Parking Demand and Land Use: Category Analysis Model

The relationship between parking demand (indicated by maximum parking accumulation) and land use intensity can be expressed by the following:

$$BP_{ik} = f(L_{ik}) = \alpha_i L_{ik} \tag{1}$$

TABLE 1 Order of Reasons for Bicycle Parking

Reason		Selected order 1	2	3	4	Weighted average of order
walking dist.		634	128	21	7	1.24
	(%)	80.3	16.2	2.7	0.9	
security		104	378	208	100	2.39
	(%)	13.2	47.9	26.3	12.7	
acceptable fee		25	265	327	173	2.82
	(%)	3.2	33.5	41.4	21.9	
difficult to find		27	124	208	431	3.32
other places	(%)	3.4	15.7	26.3	54.6	

where

BP_{ik} = maximum parking accumulation in land use Type i of Zone k,
L_{ik} = intensity of land use for land use Type i of Zone k, and
α_i = parking demand rate of land use Type i.

Total bicycle parking demand at peak hour BP_k for a zone is

$$BP_k = \sum BP_{ik} = \sum \alpha_i L_{ik} \quad (i = 1,2,\ldots,m) \tag{2}$$

Parking demand in n zones can be formulated as the following expression:

$$\mathbf{BP} = \boldsymbol{\alpha}\ \mathbf{L} \tag{3}$$

where

BP = vector of bicycle parking demand,
α = parking demand production matrix, and
L = land use intensity index matrix.

Basic year **BP** and **L** collected in CCA of Shanghai can be input to calibrate **α** in Equation 3. The algorithm used in model calibration is nonlinear programming, that is, an objective function and constraint condition are selected. The nonlinear programming model can be expressed as the following:

Objective function:

$$\min f_m = \sum (BP_k - \sum \alpha_i L_{ik})^2 \tag{4}$$

Subject to

$$\alpha_i \geq 0 \quad \begin{matrix}(i = 1,2,\ldots,m)\\(k = 1,2,\ldots,n)\end{matrix}$$

The index of Demand Model α_i (see Table 3) is calibrated by inputting the maximum parking accumulation and employee numbers of 13 land use types in 14 zones of the CBD of Shanghai that were surveyed in the basic year (1987). To solve Equation 4 is to iterate the algorithm by computer model until the precision

TABLE 2 Tolerant Values of Bicycle Parking Service

Section of tolerant value		Acceptable percentage for different trip Purposes (%) Work	Shpg	Bsns	Rcrt	Othr	Sum	Number of sample
Walk dist.	<100	8.5	10.9	8.0	1.3	6.5	35.1	780
	100-300	11.9	9.2	6.7	1.2	10.5	39.5	
(meter)	300-600	3.9	3.5	1.9	0.6	4.7	14.6	
	600-900	1.3	0.8	0.4	0.1	1.8	4.4	
	>900	3.7	0.1	1.0	0.1	1.4	6.4	
Parking fee	<0.05	1.2	1.5	0.4	0.3	3.4	6.7	742
	0.05-0.1	14.6	12.4	8.9	3.2	12.7	51.8	
	0.1-0.2	9.6	6.2	7.8	1.4	7.8	32.8	
(yuan)	0.2-0.3	1.9	2.4	1.9	0.4	0.4	7.0	
	>0.3	0.1	0.4	0.9	0.0	0.3	1.7	
Critical	1/2-1	23.1	19.0	15.2	3.4	17.3	78.0	764
transit	1-3/2	3.8	4.3	2.9	1.1	3.5	15.6	
transfer	3/2-2	1.7	0.8	0.5	0.3	1.8	5.1	
time ratio	>2	0.5	0.4	0.0	0.1	0.3	1.3	
Critical	<1/4	4.5	4.3	3.8	0.9	3.8	17.3	445
motorcycle	1/4-1/2	12.8	15.3	8.1	1.4	8.8	46.3	
transfer	1/2-3/4	10.8	5.4	5.2	0.7	7.9	29.9	
time ratio	3/4-1	1.6	2.7	0.9	0.0	1.4	6.5	

TABLE 3 Forecast of Bicycle Parking Demand for Different Land Uses in Shanghai CBD, 2000 (4)

Zone	1 House hold	2 Heavy indst	3 Light indst	4 Colleg	5 High Schl	6 Admn Offc	7 Busn	8 Recre	9 Hotel	10 Ware-house	11 Const side	12 Hospl	13 Other	Total
α_i	0.038	0.023	0.05	0.099	0.011	0.242	0.100	2.087	0.010	0.080	0.011	4.069	0.011	
0101	8.7	22.5	226.0	11.4	2.4	1982.0	274.9	377.8	0.0	15.1	3.1	590.0	3.7	3517
0102	19.6	10.1	209.8	11.1	10.6	767.5	1472.9	943.5	22.8	14.9	3.5	596.6	6.1	4061
0103	5.3	4.0	60.6	18.6	4.0	294.9	228.3	2452.7	0.0	17.0	6.1	150.5	10.5	3252
0104	19.7	10.7	123.6	11.4	3.9	199.8	250.1	77.2	0.0	8.8	1.5	447.6	2.7	1157
0105	11.1	1.7	98.5	0.0	2.4	245.4	296.3	711.8	11.6	3.1	2.9	451.6	4.3	1841
0106	13.1	6.7	119.7	18.5	4.6	33.9	432.2	837.0	11.5	8.4	3.9	606.2	5.3	2401
0107	25.0	88.5	621.0	41.2	16.2	950.1	1296.1	1795.2	30.2	32.9	6.2	1066.0	8.1	5976
0108	8.4	17.4	142.8	28.5	6.9	1414.5	382.2	77.2	15.5	23.6	7.5	1224.7	2.0	3351
0109	12.3	4.2	103.7	4.1	3.5	834.2	657.9	75.2	3.7	18.0	3.0	455.7	8.5	2184
0110	4.2	7.5	87.4	6.7	3.2	1315.6	271.9	81.4	0.0	6.2	1.6	313.3	2.9	3873
0111	2.8	14.9	143.0	0.0	3.2	2174.0	302.5	761.9	3.7	11.2	9.9	447.6	2.9	3878
0112	5.5	2.4	111.2	7.2	2.4	809.5	287.2	148.2	14.8	2.9	1.1	150.5	3.7	1546
0113	10.8	0.9	47.2	0.0	1.9	126.8	343.9	1173.1	7.5	3.0	5.3	0.0	7.2	1727
0114	12.5	36.3	256.8	40.9	5.1	1190.5	510.3	548.9	15.4	27.4	3.4	1236.9	3.7	3888
Total	159	227	2351	199	70	12639	7006	10061	137	193	59	7710	72	40881

of the result is acceptable. If land use data of the particular year are available, the demand for bicycle parking in the CBD can be estimated using Equations 2 and 3 and the index of demand model in Table 3.

The number of employment positions in the CBD in the year 2000, as shown in Table 4, is available from the comprehensive urban plan of Shanghai (*1*). Included with those data are the estimated numbers of bicycle parking spaces needed for the future (Table 3).

Relationship Between Parking Demand and Bicycle Trip Attraction: Linear Regression Model

Demand for bicycle parking will be produced wherever there is an end to a bicycle trip. Obviously, the greater the trip attraction, the greater the need for bicycle parking. The relationship between parking demand and trip attraction is shown in Figure 7. Assuming that there is a linear relationship between bicycle trip attraction and bicycle parking demand,

$$BPN_k = a + b\,DB_k \qquad (5)$$

where

BPN_k = maximum bicycle parking accumulation in Zone k;
DB_k = bicycle trip attraction in Zone k; and
a,b = regression factors.

Regression factors a and b are calibrated by inputting basic year data from 14 sets of BPN_k and DB_k in the CBD:

$a = -136.59$

$b = 0.1829$

Relative factor $R = 0.88$

The model passed the t-test and the F-test.

Parking demand in the year 2000 also can be obtained from the above model if the number of bicycle trip attractions in that year is available (see Table 5).

Comments on Bicycle Parking Demand Modeling

The land use approach is widely used to forecast transportation demand. It is also used to predict the demand for bicycle parking. Comparing it with the land use–related model, the output of the trip attraction–related model does not directly link to land use parameters, but trip attraction is estimated using a land use parameter as an independent variable. Finally, the demand in parking is a function of the land use.

The total demand for bicycle parking in the CBD of Shanghai calculated by the category analysis model is 40,881; calculated by the linear regression model, it is 38,193. The difference between these two results is only 6.5 percent. Such a small variation shows that one model can be a proof to the other, although the models are set up differently. Thus the models are reliable in forecasting future bicycle parking demands.

Two models have different functions: the land use–related model is more likely to become the standard for bicycle parking spaces with different land use types, whereas the trip attraction–related model can be applied to quick-response parking demand estimation during the urban transportation planning process.

BICYCLE PARKING PLANNING AND STRATEGY

Quantitative analysis of bicycle parking in the CBD made the situation more understandable. Bicycle parking demands in a specific period can be figured out using the models mentioned earlier. The studies show that the quantity of bicycle parking demands surpasses the facilities that can meet the demands in this area. The fundamental way to overcome the shortage is to provide efficient facilities while controlling the demand.

Analysis of Shortage of Parking Facilities in Shanghai CBD

Shortage of Facilities

Nearly all the zones in the CBD bicycle parking are oversaturated during the peak period simply because of insufficient parking facilities. There are 275,000 bicycles registered in the CBD, and 150,000 to 180,000 bicycle trips are made to this area. But the area of total parking facilities for both motor vehicles and bicycles is only 55,000 m^2—only about 1.3 percent of the CBD area. Furthermore, there is no standard public garage or parking lot for bicycles.

Inefficient Parking Management

There is neither a form of authority and enough responsible staff to manage bicycle parking in the CBD nor a practicable policy and law to restrain bicycle parking. Many parking lots are unable to run because of the high cost.

Illegal Road Occupancy and Parking

Many bicycle riders ignore the traffic signs and park their bicycles casually. In addition, some foot vendors stand their bicycles and hawk their wares on the street.

Planning Bicycle Parking and Managing Measurement

Comparing the available bicycle parking facilities with the parking demand that is predicted using the earlier model indicates that there will be a shortage of 20,000 bicycle parking spaces in the year 2000. The way to solve the problem is to combine reasonable planning and effective demand control in this region.

Plan To Build Public Bicycle Parking Facilities

To keep the balance between parking demands and land use resources, five public bicycle garages are planned in the CBD (see Figure 8). The largest one (about 5,000 m^2) will be located at the People Square, the hub of public transit (subway and bus line). An increase of 13,000 parking spaces will be produced by the plan.

TABLE 4 Predicted Employment in Shanghai CBD, 2000 (*1*)

Zone	1 House hold	2 Heavy indst	3 Light indst	4 Colleg	5 High Schl	6 Admn Offc	7 Busn	8 Recre	9 Hotel	10 Ware- house	11 Const side	12 Hospl	13 Other	Total
0101	230	997	4687	115	227	8173	2743	181	0	188	291	145	332	17353
0102	519	446	4352	112	1005	3165	14688	452	226	185	332	140	557	24739
0103	142	180	1256	188	376	1216	2278	1175	0	212	579	37	957	6811
0104	523	475	2563	116	369	824	2495	37	0	110	141	110	252	7402
0105	295	74	2044	0	224	1012	2956	341	115	39	276	111	394	6946
0106	347	299	2483	187	438	1377	4312	401	114	105	374	149	484	9844
0107	664	3930	12882	416	1534	3918	12931	860	299	409	587	262	737	37135
0108	223	771	2962	288	664	5833	3813	37	153	294	713	301	185	14591
0109	327	186	2150	41	337	3440	6564	36	37	224	287	112	770	13081
0110	110	332	1813	68	302	5425	2713	39	0	77	151	77	266	10802
0111	73	660	2967	0	302	8965	3018	365	37	140	947	110	265	16350
0112	147	107	2307	73	227	3338	2865	71	147	37	100	37	332	9135
0113	286	39	979	0	184	523	3431	562	74	37	500	0	651	6004
0114	331	1610	5327	413	482	4909	5091	263	152	341	324	304	340	18426
Total	4217	10106	48772	2017	6671	52118	69898	4820	1354	2399	5602	1895	6522	198619

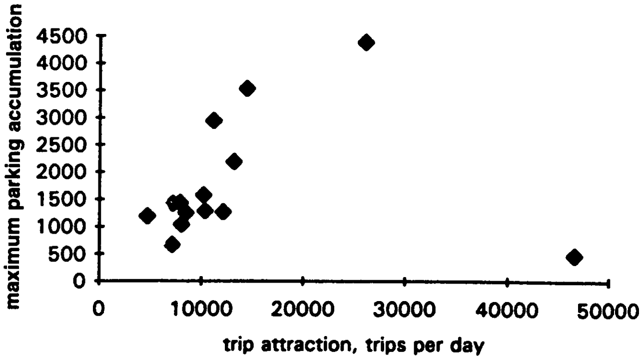

FIGURE 7 Bicycle trip attraction and parking demand in Shanghai CBD.

Administration authorities should provide a policy that would encourage developers to invest in bicycle parking facilities and make the construction, operation, and management an attractive business.

Restricting On-Street Bicycle Parking

Arranging an on-street bicycle parking lot while considering local conditions is the effective way to provide a short walking distance (within 200 m) and temporal parking at a lower cost. The capacity of a potential on-street parking lot is 5,000 bicycles, but inefficient control of on-street bicycle parking will disturb traffic greatly, especially where it is close to the arterial. Bicycle parking on the streets across the arterial should be restricted within 50 m of the intersections.

Work Parking

All employers in the CBD should provide bicycle parking spaces for their employees. Occupancy of the public parking space for work parking is forbidden and should be fined.

Short-Term Bicycle Parking Improvements

It will take a long time to realize the CBD bicycle parking plan. A pressing need to alleviate the shortage of CBD bicycle parking facilities is short-term improvements, such as strengthening the management, rigorously enforcing payment for parking, and restricting the parking demand. The following policies and measures will be exercised:

1. Establish an authority responsible for rectifying and enforcing the plan. The functions of the authority are to work out a scheme, examine and approve the business of a parking garage and parking lot, set up the parking payment standard, and participate in developing a large public garage.
2. Use societal resources to improve the bicycle conditions in the CBD. Encourage residents to open vacant lots for temporal bicycle parking with the help of a favorite policy and subsidy so as to increase the available parking spaces in urgent-need areas.
3. Adjust the parking demand by using economic levers. A parking toll system should be set up according to the differential price of land. All bicycle owners should be levied extra taxes and all bicycle riders should have to buy a special license plate if they enter the CBD.

SUMMARY

Bicycle parking, an important component of the transportation process in China, merits extensive investigation. Some of the important regular patterns of bicycle parking in the CBD, such as the relationship between parking demand and facility supply and the character of bicycle parking behavior have been revealed. In addition, because of the continuous study in the CBD and CCA of Shanghai, the relationship between land use parameters has been modeled and calibrated. All of these achievements are the

TABLE 5 Bicycle Parking Trip Attraction and Maximum Parking Demand in Shanghai CBD

	Survey Value(1987)		Forecasting Value(2000)	
Zone	Trip attraction	Max. parkg Accumulation	Trip attraction	Max. parkg Accumulation
0101	7180	1420	12717	2189
0102	26039	4399	33460	5983
0103	10362	1285	15770	2748
0104	12110	1269	13768	2382
0105	13196	2197	18303	3211
0106	11147	2942	19404	3412
0107	14455	3533	25906	4602
0108	8027	1040	6984	1141
0109	10194	1579	18471	3242
0110	4662	488	7884	1305
0111	7121	667	8615	1439
0112	4699	1192	6468	1046
0113	8483	1254	17291	3026
0114	7898	1441	14234	2467
Total		24706		38193

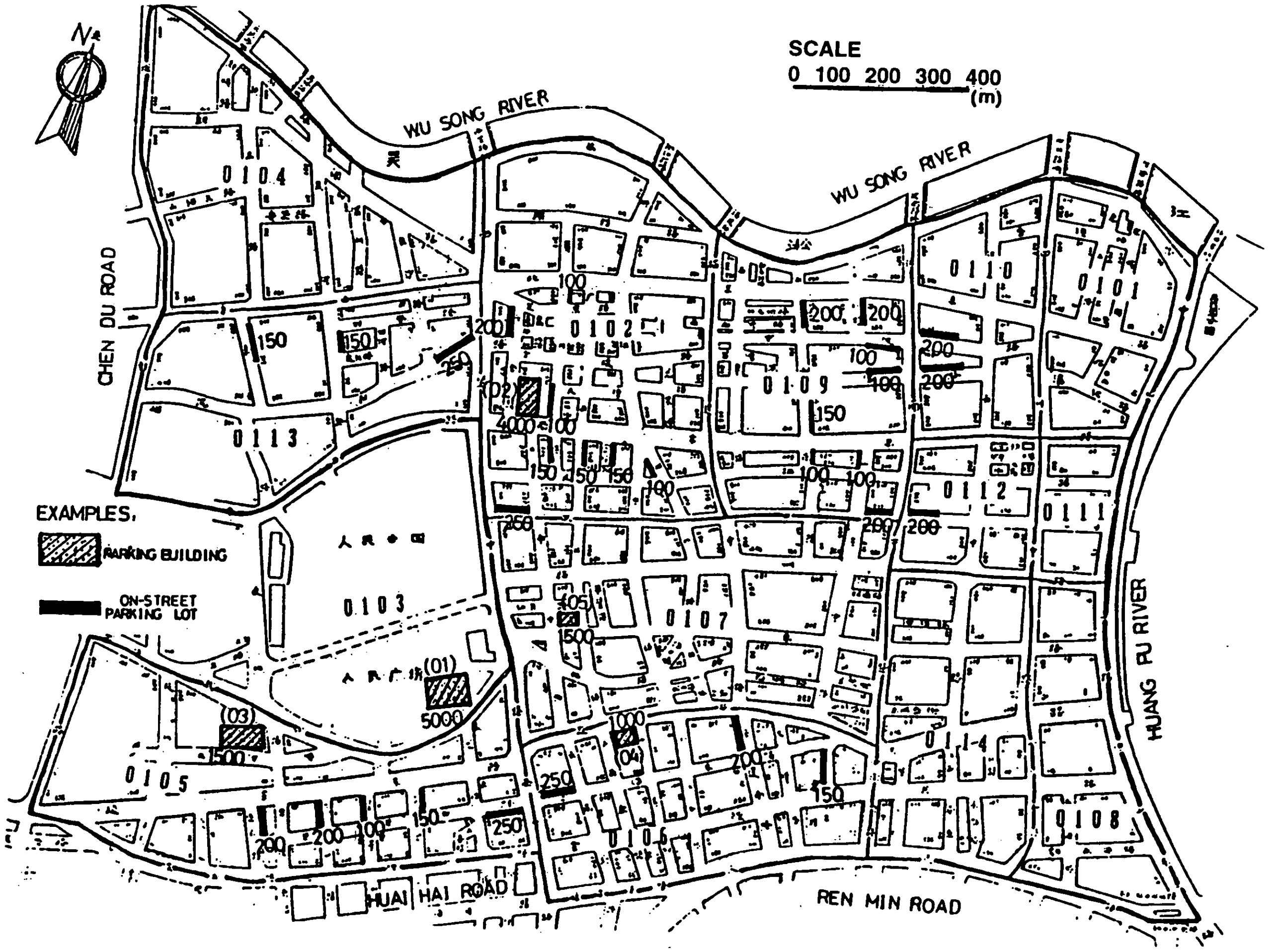

FIGURE 8 Plan for bicycle parking spaces in Shanghai CBD.

bases of demand forecasting, bicycle parking planning, management, and facility operation.

The main methods to alleviate the bicycle parking facility shortage and to maintain the equilibrium of supply and demand are to distribute the facilities in a rational manner and effectively control the excessive demand in this area. The package provided is feasible in most cities of China, where bicycle riding is the principal travel mode.

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